Analysis and Modeling of Target Echo and Reverberation: FY15 Annual Report for ONR

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LONG-TERM GOALS

From an operational perspective clutter is one of the most important problems facing active sonar in shallow water. The long-term objective of this work is, through quantitative model-data comparisons, to better understand target echo, clutter and reverberation in shallow water environments, and to develop techniques and models for multistatic sonar, rapid environmental assessment and environmentally adaptive sonar.

OBJECTIVES

This project is a continuation of previous efforts on analysis of reverberation, target echo, and clutter measurements in shallow water, and the interpretation and quantitative understanding of the results through modeling. The main focus is the high-quality data obtained in the 2013 Target and Reverberation experiment (TREX) in the Gulf of Mexico. Joint collaboration is continuing with scientists at the Applied Research Laboratory of Penn State University (ARL/PSU), and new collaborations established with scientists at the Applied Physics Laboratory of the University of Washington (APL/UW). Additional collaboration will continue with Defence R&D Canada, and TNO in the Netherlands. There is a lot of community interest in the reverberation data, and the Principal Investigator (PI) will collaborate in data analysis and modeling. An area of particular interest is the target echo, which has not yet received a lot of attention, and for which good data were obtained during the TREX experiments.

The main goals are:

– Participate in the analysis of the reverberation and target echo data
– Attempt to determine the underlying mechanisms and quantify them through modeling
– Rework the normal mode propagation and reverberation models
– Analyze the target echo returns, and model the time spreading
– Refine and extend the normal-mode range-dependent reverberation and clutter modeling.

APPROACH

These TREX measurements [TH12, HT14] have provided an extensive set of high quality data for follow-on modeling and validation. The reverberation data were taken over a four-week period, with low to moderate sea states, generally including measurements at night. The TREX target echo data are good quality, with very little available in the literature. The TREX data appear to be excellent, and with the extensive supporting environmental information, this is a superb opportunity for advancing the understanding of reverberation and target echo.

One thing already discovered [EYPP14] along the main track is that, counter-intuitively, the higher reverberation seems to be correlated with the troughs of sand dunes rather than the peaks, so there is some interesting physics to be explored and explained. It could be different surface scattering, but another possibility is sub-bottom scattering which the PI has had some experience modeling [EDT97, HE09, HE12]. The PI is developing a target echo model, including time spreading of the echo, to be validated against data.

The PI is spending one month each year collaborating as a visiting scientist at each of ARL/PSU and APL/UW.

WORK COMPLETED

This section summarizes some of the work completed in FY 2015.

The previous ONR award N00014-11-1-0476 has been completed [Ell15], and the current one was initiated in 2015. In the spring of 2015 the PI spent one month at ARL/PSU, working on TREX data processing with John Preston, and doing range-dependent modeling with Charles Holland. The PI is also spending one month at ARL/UW, working on TREX transmission loss, reverberation, and target echo with DJ Tang, Todd Hefner, and Jie Yang.

The focus of the PI's work has been the analysis and modeling of the reverberation and target echo data from the TREX13 experiment: [EPB12, EP13b, EP13a, EYPP14].

The data from the GulfEx12 experiment had suggested a correlation of reverberation with sand dunes [EP13a], and preliminary analysis during the TREX13 sea trial had indicated a correlation of the reverberation peaks with the troughs of the sand dunes rather than the crests. More careful analysis was done post-trial, and indeed that turned out to be the case [EYPP14, PET14]. As part of the analysis, predictions were made along the reverberation track with an adiabatic normal mode reverberation model. These showed correlation of reverberation peaks with the crests of the sand dunes – as expected – but opposite to the data. The PI presented an invited paper [EP14] at the Indianapolis meeting of the Acoustical Society of America in October 2014 and attended the follow-on TREX Workshop. An effective scattering strength along the track was extracted; an example given in the "Results" section below. Current efforts are to improve on those estimates with better modeling. The PI will be presenting a paper [EP15] at the Jacksonville meeting of the Acoustical Society of America meeting in November 2015 and attending a short TREX meeting.

Additional work was done to determine the calibrations of the FORA beamforming and matched filter output. Some notes are in the PI's presentation at the December 2013 TREX Workshop, but there are still differences that need to be resolved between the ARL, APL and DRDC processing results.

A new normal-mode code has been developed to replace a previous one [Ell85], developed in 1978 and updated in 1989. The computational engine is a Fortran 95 subroutine, so will be a key part of improved range-dependent reverberation and clutter models, and should also be available to imbed in C, C++, and Java applications.

In previous years the ONR Reverberation Modeling Workshops [PT07, TP08, PT09] and the UK Workshop on Sonar PerformanceTools [Ain10] have been a focus for collaboration. Extensive comparisons were made between energy-flux, normal mode, ray-based models, and analytical approaches for the Pekeris model with Lambert bottom scattering; some results had been presented previously [AEH11], and after many delays a journal paper is now in press [AEH15]. A few examples are given in the “Results” section below.

Range-dependent reverberation and target echo modeling is important, and adiabatic modes is likely to break down at some point [Ell11, EP12]. Collaborative work on a parabolic equation approach was presented at the Seabed and Sediment Acoustics Conference in Bath, UK, in September 2015 [TBHE15], and is ongoing.

RESULTS

This section illustrates a few results from the activities mentioned in the previous section.

Comparison of various methods for reverberation calculations

Stimulated by the ONR Reverberation Modeling Workshops [PT07, TP08, PT09] and the UK Workshop on Sonar PerformanceTools [Ain10], extensive comparisons were made between energy-flux, normal mode, ray-based, and analytical approaches for the Pekeris model with Lambert bottom scattering; some results had been presented previously [AEH11], and a journal paper is now in press [AEH15]. Figure 1 shows an example from Workshop Problem XI, extended to longer times (1000 s), and to very short times including the direct arrival at approximately 0.1 s. Results for the three frequencies show an almost seamless (though not perfect) agreement between the PI’s normal mode model at long time/ranges, the energy flux (or hybrid) approach, and a semi-coherent ray approach [Ell12] at short times. While we hesitate to call this a “benchmark”, it is a reference solution for other reverberation models to compare against.

Effect of different separable approximations

Comparing various solutions to Problem XI, except at short times the normal mode approach using group velocities to approximate the travel time [Ell95] seems the most accurate. However, for computational efficiency and for the energy flux approach, it is very useful to approximate this solution with a separable expression. Ellis provided one [Ell95], but in the analysis for Problem XI Ainslie developed an improved separable approximation [AEH15]. Ainslie also independently determined [Ain13] that previous reverberation formulations (including [Ell95]) should have an extra cosine term.

These two results are illustrated in Fig. 2. The black line is the difference between the two group velocity results and increases steadily to just over 0.5 dB as the time/range approaches 0. It flattens at very short times since the normal mode expressions essentially cut off all paths steeper than the critical angle. The coloured lines lines correspond to the differences between the group velocity formulation and the two separable approximations. The blue lines correspond to the original separable approximation of Ellis; the green lines correspond to the improved separable approximation of Ainslie

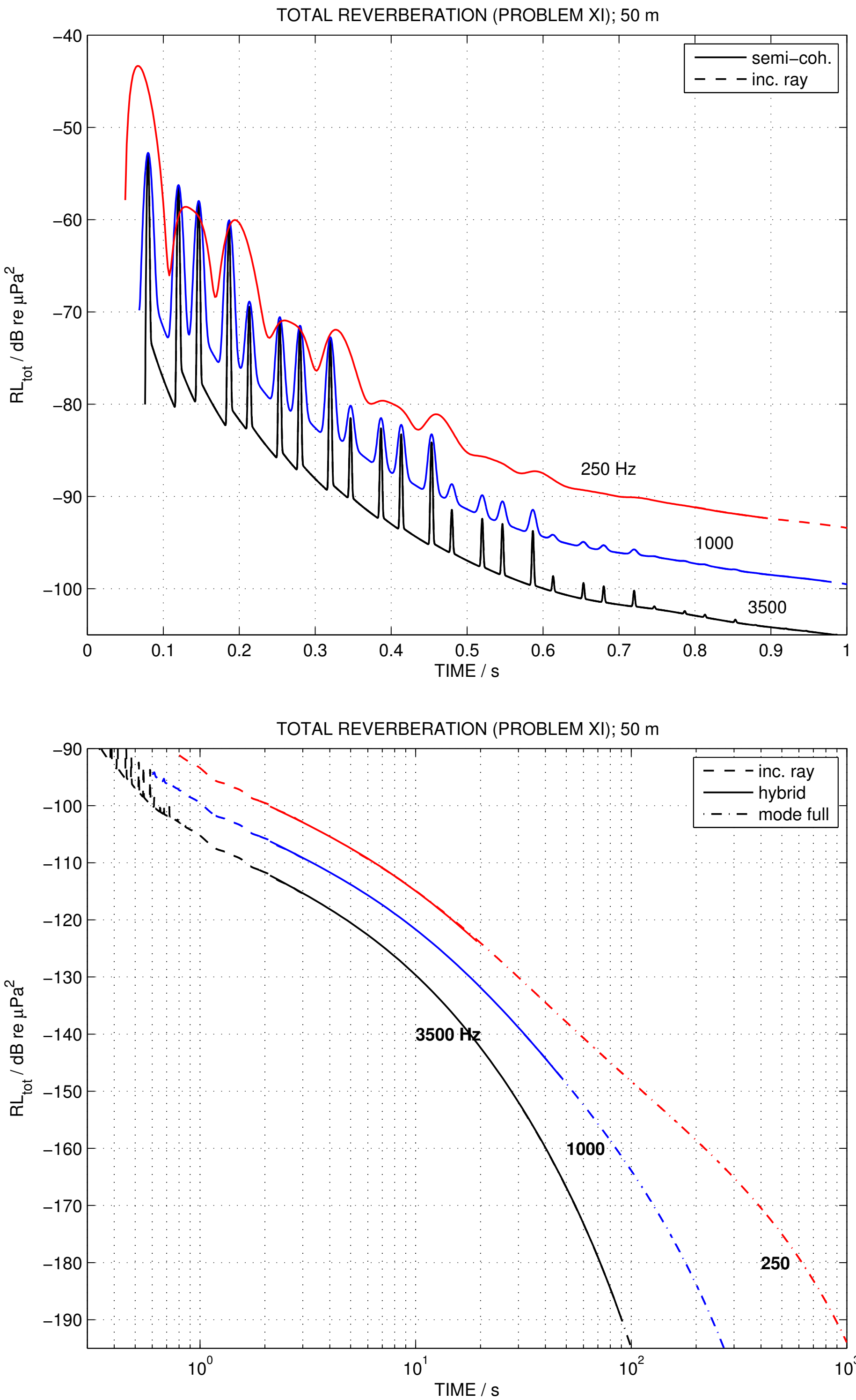

Figure 1: Comparison of various methods for reverberation calculations for Reverberation Workshop Problem XI at 3 frequencies. The bottom graph shows longer times, to 1000 s; the upper graph shows results at very short times. The various models show very good agreement. Note also the "bulge" in the 250 Hz calculation around 300 s, which is a mode effect.

et al. The maximum error for the separable approximations occur at about 10 s, and is quite small; Ainslie's separable expression is about twice as good there.

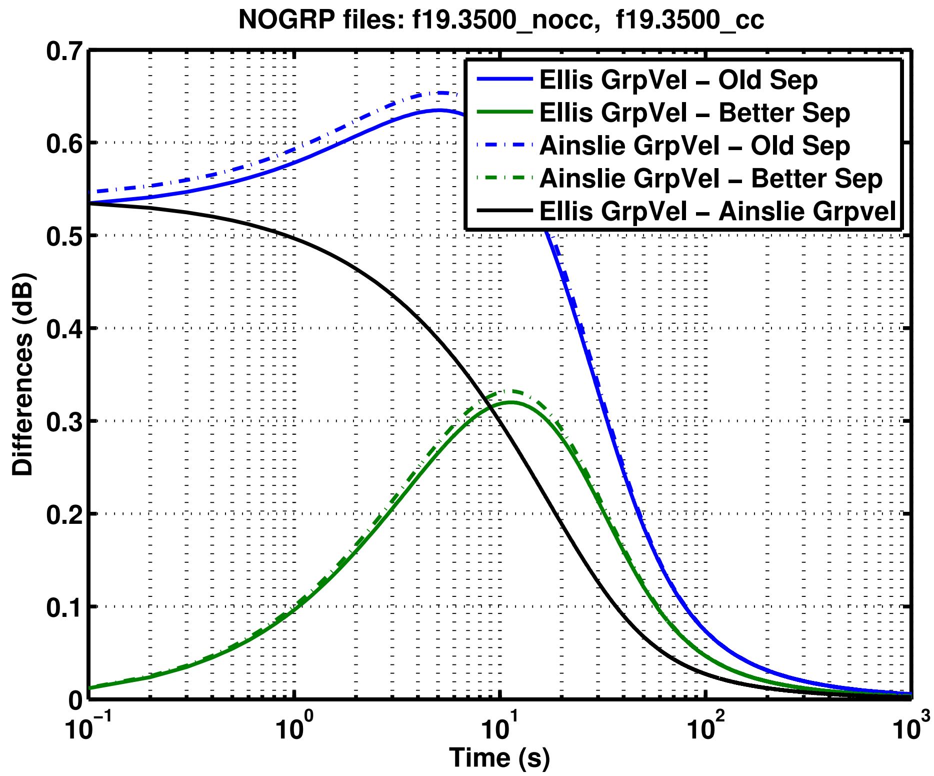

Figure 2: (Black) Differences of reverberation predictions using normal mode the group velocity formulation, with and without Ainslie's cosine correction [Ain13]. (Blue) Error in the Ellis [Ell95] separable approximation compared to the group velocity reverberation: without (solid line) and with (dashed line) the cosine correction. (Green) Error in the Ainslie separable approximation compared to the group velocity reverberation: without (solid line) and with (dashed line) the cosine correction.

Implied scattering strength for the TREX main reverberation path

The PI's adiabatic mode range-dependent reverberation model [Ell11] was used to compare with measured reverberation along the TREX main reverberation path [EYPP14, EP14]. The model predicts that for uniform scattering, the peaks of the reverberation should lie on the crests of the sand dunes. However, the data show that the high scattering is coming from the troughs; thus the enhancement is not due to the bathymetry, but an increase in the intrinsic scattering. Figure 3 shows the implied scattering strength for the TREX main reverberation path. Even when averaged over multiple pings the enhancement is 5–10 dB. The scattering mechanism is not determined, but the PI is working to extend his model to handle volume reverberation in the bottom [EDT97].

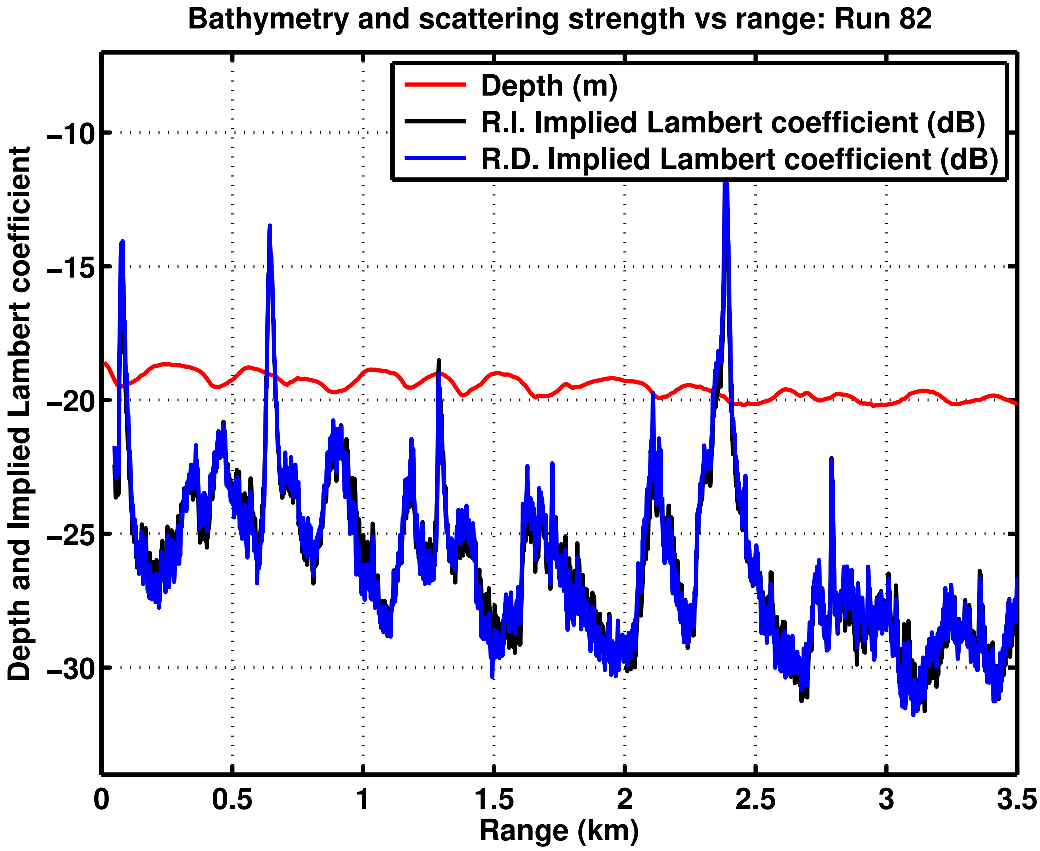

Figure 3: Implied scattering strength for the TREX main reverberation path. There is enhanced scattering from the troughs between the sand waves. This enhancement is not due to the bathymetry, but some change in the intrinsic scattering.

IMPACT/APPLICATIONS

In terms of naval relevance, clutter is viewed as one of the most important problems facing active sonar in shallow water. The long-term objective of this work is to better understand and model reverberation and clutter in shallow water environments, and to develop techniques for Rapid Environmental Assessment (REA) and environmentally adaptive sonar.

The TREX data are a valuable tool in validating models, and determining the effect of the environment.

TRANSITIONS

In an operational concept, a computational Clutter Model would produce towed array beam time series, which would then be subtracted from the corresponding measured beam time series. The differences would then be overlaid on a bathymetry map, producing hot spots of model-data differences. Ideally, the range-dependent model would quantitatively predict the effects known bathymetric features and clutter objects, leaving a small number of unknown clutter objects and targets that could then be investigated and classified using other techniques (such as auralization) to try to determine their nature. If the target echo model can be validated, this could be a useful method for estimating the target strength of clutter features—and even submarines—in multipath shallow water environments.

RELATED PROJECTS

This collaboration ties in with other projects at ARL, APL and DRDC Atlantic. Though retired from DRDC, the PI is remaining active in research activities. He has been appointed adjunct professor in the Physics at Mount Allison University and the Department of Oceanography at Dalhousie University, where he is on the advisory committee of a PhD student. He continues to collaborate with DRDC colleagues and TNO scientists.

He is also associated with Maritime Way Scientific Limited of Ottawa, Canada, who are hoping to collaborate with defence contractors provide sonar modeling systems for naval applications.

PUBLICATIONS

The following publications were submitted, accepted or published during the past year:

- Michael A. Ainslie, Dale D. Ellis, and Chris H. Harrison. Low frequency bottom reverberation in a Pekeris waveguide with Lambert's rule. *J. Comp. Acoust.* [in press]
- D. J. Thomson, G. H. Brooke, C. Hamm, and D. D. Ellis. A spectral decomposition procedure for determining the fields at the boundaries in a PE-based reverberation model. *Proc. Institute of Acoustics*, 27, Pt. 1:118–126, 2015. From conference on Seabed and Sediment Acoustics held at University of Bath, UK, 7–9 September 2015. [published]

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